

Chapman University Chapman University Digital Commons

ESI Working Papers

Economic Science Institute

1-22-2019

Endogenous Market Formation and Monetary Trade: An Experiment

Gabriele Camera

Chapman University, camera@chapman.edu

Dror Goldberg

Open University of Israel

Avi Weiss

Bar-Ilan University

Follow this and additional works at: https://digitalcommons.chapman.edu/esi_working_papers



Part of the [Econometrics Commons](#), [Economic Theory Commons](#), and the [Other Economics Commons](#)

Recommended Citation

Camera, G., Goldberg, D., & Weiss, A. (2019). Endogenous market formation and monetary trade: An experiment. ESI Working Paper 19-04. Retrieved from https://digitalcommons.chapman.edu/esi_working_papers/261/

This Article is brought to you for free and open access by the Economic Science Institute at Chapman University Digital Commons. It has been accepted for inclusion in ESI Working Papers by an authorized administrator of Chapman University Digital Commons. For more information, please contact laughtin@chapman.edu.

Endogenous Market Formation and Monetary Trade: An Experiment

Comments

Working Paper 19-04

Endogenous Market Formation and Monetary Trade: an Experiment*

Gabriele Camera
Chapman University
University of Bologna

Dror Goldberg
The Open University of Israel

Avi Weiss
Bar-Ilan University
Taub Center for Social Policy Studies in Israel
IZA

January 22, 2019

Abstract

The theory of money assumes decentralized bilateral exchange and excludes centralized multilateral exchange. However, endogenizing the exchange process is critical for understanding the conditions that support the use of money. We develop a “travelling game” to study the emergence of decentralized and centralized exchange, theoretically and experimentally. Players located on separate islands can either trade locally, or pay a cost to trade elsewhere, so decentralized and centralized markets can both emerge in equilibrium. The former minimize trade costs through monetary exchange; the latter maximizes overall surplus through non-monetary exchange. Monetary trade emerges when coordination is problematic, while centralized trade emerges otherwise. This shows that to understand the emergence of money it is important to amend standard theory such that the market structure is endogenized.

Keywords: endogenous institutions, macroeconomic experiments, matching, coordination, markets, money.

JEL codes: E4, E5, C9, C92

* We thank Co-Editor Imran Rasul and four anonymous referees for many helpful suggestions and comments that substantially improved this study from an earlier version. We also thank A. Baron, A. Chachmon, I. Feder, U. Rochev and, especially, I. Dekel, for research and programming assistance, as well as seminar participants at the Technical University of Berlin, GATE-Lyon, and participants at the 2013 and 2015 SAET Meetings and the 2015 and 2018 ESA International Meetings for comments. D. Goldberg and A. Weiss gratefully acknowledge research support from the Israel Science Foundation (grant No. 1004/11). Correspondence e-mail: camera@chapman.edu

1 Introduction

In its most basic form, a model economy is a collection of individuals who exchange the fruit of their specialized labor for something they desire but cannot produce. Hence, welfare—individual and aggregate—hinges on the organization of trade. Much of economic theory assumes traders interact in a *centralized market* based on synchronous multilateral exchange. Yet, the monetary literature assumes traders interact in a *decentralized market* through asynchronous bilateral exchanges.¹

Here we ask: How would traders *choose* to organize their interactions? This question is important because the organization of trade has implications for allocations and the kind of assets that end up being traded. In particular, we are interested in money. Standard monetary theory explains the existence of money as an optimal response to the trade frictions inherent to decentralized exchange, and in particular a bilateral matching process that precludes interaction within small groups of fixed counterparts (Kiyotaki and Wright, 1989). These frictions undermine the possibility to coordinate on non-monetary equilibrium alternatives. But in the theory of money the organization of trade is exogenous: bilateral exchange is taken as a primitive, while multilateral exchange is arbitrarily restricted (Corbae et al., 2003, p. 733). This is justified as being a consequence of economic specialization, and various impediments to organizing a centralized market (Lucas, 1984). It is thus an open question to understand what conditions lend themselves to the development of money, when we lift the restrictions on centralized trade. Would traders prefer to synchronize all exchange in a single location, or bilaterally trade across space and time using money? The few existing theoretical analyses indicate that the emergence of centralized or decentralized markets generally depend on the severity of trade frictions and costs from organizing trading activity (Camera, 2000;

¹See Townsend (1980), Diamond (1984), Lucas (1984), or Kiyotaki and Wright (1989). In monetary theory, decentralized market is a situation in which spatially separated players travel to specific locations to trade asynchronously and in isolation from others, while centralized market means that everyone meets and simultaneously trades in a specific location (Hellwig, 1993; Lucas, 1984).

Goldberg, 2007). Here we design an experiment that makes these frictions and costs explicit, with the aim to investigate the principles underlying the theory of money, and not to reproduce and test a specific monetary model.

In the experiment, three specialized producers located on separate “islands” (see Fig. 1) interact over multiple rounds of play. Each produces one of three differentiated goods and derives a benefit from consuming someone else’s good. Hence, there are gains from trade. Players can travel round-trip to any island at a cost that depends on the good transported. This implies a tradeoff: the player’s payoff rises with the frequency of consumption but falls with that of travel. Surplus is created only if at least two players coordinate on where and when to meet, which is a non-trivial problem to solve because cost disparities imply conflicting incentives, and choices are made independently, simultaneously and without prior communication.

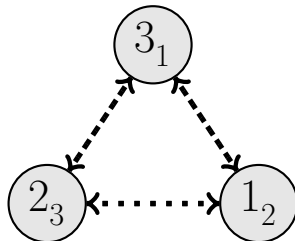


Figure 1: The travelling game

Notes: The larger number is equivalently the player’s island, type, and consumption good; the smaller is the player’s production good. The arrows denote the possible directions of travel.

In this “travelling game” exchange can take two natural forms: simultaneous and multilateral on one island, or asynchronous and bilateral across islands (Lucas, 1984). The first gives rise to a *centralized market* (CM) on the island producing the high transport-cost good; the second to a *decentralized market* (DM) supported by a monetary system in which the low transport-cost good serves an explicit medium-of-exchange function. In Nash equilibrium non-monetary CM and monetary DM trade coexist, and CM is socially efficient. Yet, there is no obvious reason to expect that one equilibrium should prevail over the other since players have conflicting incen-

tives. We thus turn to the intuitions from monetary theory to formulate predictions.

The monetary literature has put forward the notion that there is no role for money if its use cannot expand the set of payoffs (Corbae et al., 2003; Kocherlakota, 1998); the underlying idea is that individuals naturally coordinate on efficient play. Bilateral matching frictions help explain the existence of money because they undermine coordination on non-monetary equilibria. But money is used also because individuals are persistently focused on a single economic task, an extreme form of specialization that makes barter impractical (Kiyotaki and Wright, 1989). To probe these intuitions, we contrast the frictionless baseline design—where players’ roles and counterparts are fixed for the session—with treatments manipulating various aspects of the design. In one case, we periodically rematch players into new groups so counterparts randomly change during the session. In another treatment, we scale up the group in order to assign travelers to a random island of the type that they seek. These manipulations introduce trade frictions that should boost monetary exchange. Two other treatments relax the extreme form of specialization typical of monetary models: in one, players’ types rotate throughout the session, which maintains the equilibrium set unaltered but expands players’ focus from one to multiple economic tasks; in the other, producers can diversify their output and then barter it, which alters the equilibrium set but maintains the single-task focus. We also consider an environment in which commodity and fiat money compete, and pre-play communication allows explicit coordination of strategies.

We find mixed support for the intuitions from the monetary literature. In treatments with rotation, subjects learned to coordinate on conducting non-monetary trade multilaterally in a centralized market—in line with the notion that money should not be used when more efficient trading arrangements exist. When we scaled-up groups, or periodically reshuffled them, we also observe that subjects learned to coordinate on monetary trade. But, we also see that monetary DM trade, not the socially efficient CM, prevailed in the frictionless, fixed-types baseline design,

in contrast with theoretical intuitions. Moreover, centralized markets emerged as the dominant trading arrangement only when subjects could *explicitly* coordinate strategies through pre-play communication. And when we added the options to diversify and barter production, or to carry a token at no cost, barter trade and fiat monetary trade emerged, which crowded out a more efficient trading arrangement.

These observations suggest ways to improve the theory of money, which traditionally precludes multilateral centralized trade. In our experiment, relaxing that constraint inhibited the use of money, challenging the use of exogenous restrictions on the organization of trade. Yet, decentralized monetary trade was pervasive because coordination problems made organizing socially efficient CM trade challenging. This is consistent with the monetary theory view that trade is decentralized because organizing a centralized market is impractical. Subjects could coordinate on non-monetary CM through tacit means, but trade was primarily bilateral, decentralized and monetary. Type rotation mitigated coordination problems by re-aligning incentives, but CM trade prevailed only when strategic uncertainty could be managed through explicit and costless communication. The idea that the organization of exchange purely reflects a natural tendency to coordinate on efficient play is empirically problematic, suggesting that incorporating considerations about coordination problems in existing monetary theory can help reduce the disconnect between theory and laboratory data. This same insight emerges from non-monetary games (Heinemann et al., 1989; Van Huyck et al., 2007) and monetary experiments with a different design (Camera and Casari, 2014; Camera et al., 2013). A unique insight of our study is that monetary trade appears to be a resilient trading arrangement, one that is robust to allowing for multilateral trade.

2 Related experimental literature

There is a small but growing experimental literature on money, which can be organized according to two key design features: whether the market structure is taken

as a primitive or is endogenous, and whether non-monetary equilibria theoretically exist that can improve overall efficiency beyond what can be achieved through monetary trade. Table 1 situates our experiment within this literature.

Table 1: **Monetary experiments: a map**

	Cannot improve upon monetary trade	Can improve upon monetary trade
Exogenous market structure	McCabe (1989), Lian & Plott (1998), Duffy & Ochs (1999), Camera et al. (2003), Duffy & Puzzello (2014), etc.	Camera et al. (2013), Camera & Casari (2014)
Endogenous market structure	Bigoni et al. (forth.)	This study

The majority of experiments lies in the top-left quadrant, where the market structure is exogenous and monetary equilibrium lies on the (constrained) efficiency frontier. These experiments can be further subdivided into two groups, depending on whether money has intrinsic value or is a barren token. Several experiments study the endogenous valuation of a fiat money by adopting a competitive market design, as in McCabe (1989), Marimon and Sunder (1993), Lian and Plott (1998), Camera et al. (2003), Deck et al. (2006), and Huber et al. (2014). In these designs, all players operate in a market in which they must submit monetary bids to buy consumption goods, i.e., there is an explicit “cash-in-advance” constraint, which automatically imposes the use of a fiat-money system.

Other studies seek to uncover what commodity will become the medium of exchange in the bilateral random matching model of Kiyotaki and Wright (1989). Examples include Brown (1996) and Duffy and Ochs (1999), where players of three types own a good they cannot consume, but can exchange for their consumption good through a sequence of random encounters. A characteristic of these designs

is that players can consume only if they use a commodity as a money, the *only* alternative to commodity-money trade being autarky—which automatically imposes the use of a commodity-money system. By contrast, we study the emergence of a commodity-money system when autarky is not the only alternative to trade and, in fact, a non-monetary trading arrangement co-exists that increases overall surplus. This gives rise to equilibrium multiplicity, monetary and not, and therefore situates our experiment in the larger experimental literature about coordination in games (e.g., Heinemann et al., 1989; Van Huyck et al., 2007; Weber, 2006).

There are previous experimental designs that admit multiple equilibria, monetary and not, in which a monetary system is not imposed but where players face coordination problems. In some of these studies fiat monetary equilibrium lies on the efficiency frontier (Bigoni et al., 2018; Duffy and Puzzello, 2014); in others, subjects can theoretically improve overall efficiency by coordinating on a non-monetary equilibrium (Camera and Casari, 2014; Camera et al., 2013). Yet, in all of these experiments the market structure is taken as a primitive: subjects are not free to modify their environment to mitigate trade frictions. In particular, they cannot choose which or how many counterparts to meet in a round, and where to meet. This last feature differentiates our design from the only monetary experiment that, to our knowledge, endogenizes an aspect of the market structure (its size). In Bigoni et al. (forth.), homogeneous players have the option to form a large group where counterparts change at random, or to be paired to a fixed counterpart. Either way, interaction is always bilateral and asynchronous. We contribute to this investigation of endogenous trading institutions, by granting subjects the freedom to congregate with multiple counterparts, trading multilaterally and synchronously. Another innovation in the design is to consider different structures of incentives to coordinate. In the typical monetary experiment the incentives are assumed perfectly aligned across players. Instead, we consider the case in which, though everyone benefits from coordinating on some equilibrium, the incentives are conflicting.

3 Experimental design

We present the BASELINE design, and then discuss the treatment manipulations.

The travelling game: The experiment consists of a coordination task, called the *travelling game* illustrated in Fig. 1. It is played by a group of 3 subjects who can earn benefits by meeting and trading with others.

At the start of the game each subject is randomly assigned to one of three virtual islands $j = 1, 2, 3$. The island j corresponds to the subject's production and consumption *specialization type* (or simply, type): he produces one good $j + 1$ (modulo 3) that is of no value to him, and earns a benefit u only by obtaining one good j , which he consumes upon receiving it.² To earn this benefit, a subject of type j must meet and trade with a counterpart who holds good j . To do so, a subject can stay on his home island, hoping to be visited by other subjects, or can travel round-trip to another island of his choice. Travel is costly; each leg of travel with good k generates a loss c_k with $c_1 < c_2 < u < c_3$. This all but rules out travel with good 3 because travelling to trade that good is individually irrational, as it cannot generate a positive net benefit $u - c_3$. We set $u = 12$ points, while $c_1 = 1$, $c_2 = 10$, and $c_3 = 15$ points; 10 points were converted into 1 New Israeli Shekel (NIS) at the end of the experiment. Subjects played multiple rounds of this game.

A round of play: Each round is divided into two stages. In each stage subjects make independent and simultaneous choices, without communicating with others. In the travelling stage subjects see the distribution of goods across islands, must choose whether or not to travel, and, if so, to which island. Following these choices, meetings are realized: a subject can meet one or two other counterparts (=bilateral or trilateral meeting), or can remain unmatched. Matched subjects proceed to the trading stage, in which they participate in a direct mechanism that allows them to

²The terminology in the sessions is less technical: player 1 is a *Fisherman* who produces *fish* and consumes *fowl*, player 2 is a *Farmer* who produces *bread* and consumes *fish*, and player 3 is a *Hunter* who produces *fowl* and consumes *bread*.

re-allocate their goods (=trade). Roughly speaking, trade takes place if and only if there is consensus about the proposed reallocation from all parties involved; otherwise, everyone exits the meeting with the good they carried. Unilateral transfers are assumed away, to capture the main feature of the standard monetary model where all exchanges are *quid-pro-quo* (Ostroy and Starr, 1990; Starr, 1972). Hence, in a meeting there can be either trade or “autarky,” as discussed below.

In a bilateral meeting, subjects simultaneously choose whether or not to swap their goods. In a trilateral meeting where all good types are available subjects are given the option to reallocate goods from producers to consumers (=trading chain). Absent mutual consent, or if not all good types are available in the meeting, then the player who did not travel can propose a bilateral trade to someone else. Hence, in a trilateral meeting there are three possible outcomes: there is either one trilateral trade, one bilateral trade, or no trade at all.

Subjects cannot hold more than one good at a time and cannot dispose of it. Round-trip travel implies that everyone starts each round on their home island with some good. Those who consume have no inventory for the return trip (so, no cost), and start the next round with a new production good. Those who do not consume bring their end-of-round inventory into the next round.

A session: Each session involves a multiple of 3 participants (min = 6, max = 27, depending on subjects’ availability). At the session start subjects are divided into *interaction groups* of three, and each subject is randomly assigned a type 1, 2 or 3. In the BASELINE design groups and types are fixed for the session. Denoting *economy* the set of participants who can meet during a session, economy and interaction group correspond when groups are fixed.

Each session consists of at most six sequences of the travelling game (six blocks). A block starts and terminates simultaneously for everyone in the session. Each block is composed of an uncertain number of rounds of the travelling game. Subjects are informed that they will play six rounds, and from then on, after each round the

block will continue with probability 0.75, and otherwise it will stop. The expected duration of each block is thus 9 rounds. A computer randomly selected an integer number between 1 and 100 from a uniform distribution, and displayed it to subjects. The block terminated when a number greater than 75 was selected. We can interpret the probability 0.75 as the geometric discount factor of a risk-neutral subject. When a block stopped a new one started if there was sufficient time left in the session; otherwise, the session ended. Subjects were informed of this procedure and that they would play at most six blocks.

Other treatments: We have run eight additional treatments. Four treatments manipulate stability of types and of counterparts, and the others manipulate different aspects of the environment; see Table 2.

Table 2: Treatments

	Fixed types	Rotating types
Stable counterparts	BASELINE CHAT FIAT	BASELINE-R No CM BARTER
Unstable counterparts	REMATCH LARGE	REMATCH-R

In BASELINE, three counterparts interact for the whole session. In REMATCH and REMATCH-R, counterparts are unstable as session participants are randomly reassigned to a three-player group at the start of each block, using a strangers matching protocol; hence, an economy comprises multiple groups (from 2 to 9 depending on the size of the session). In LARGE, counterparts are unstable because we scale up the interaction group to be between 12 and 24, and use strangers matching in each round to allocate travelers to islands. Someone who selects to visit island j is placed

with equal probability in any of the multiple islands of type j , so players cannot choose to meet a specific counterpart (details in Supplementary Information).

In BASELINE, the subject’s type is fixed for the session, so each individual is persistently focused on a single economic task. This extreme form of specialization is typical of monetary models, and it is assumed to preclude barter (e.g., Kiyotaki and Wright, 1989). We relax this assumption in BASELINE-R and REMATCH-R. Here, the participant’s type rotates with each new block (e.g., 1,2,3; 2,3,1; 3,2,1, etc.) so each subject can produce and consume all good types during the session. This alternation in economic tasks can be seen as a form of diversification (less specialization), which is theoretically inconsequential—it does not expand the equilibrium set and, in particular, it still precludes barter. We expand the equilibrium set in the BARTER treatment, which alters BASELINE-R by giving subject j the option to switch production good—from their specialty good $j + 1$ to $j - 1$ (modulo 3)—at a cost of 2 points. This cost-variety tradeoff lets producers diversify production in order to satisfy their consumption needs through barter, capturing the idea that diversification is instrumental to barter (Camera et al., 2003).

In the aforementioned treatments there are multiple equilibria but subjects cannot explicitly coordinate their strategies. To study the impact of coordination and strategic uncertainty issues we ran the CHAT treatment, where we augment the BASELINE design by giving subjects the ability to explicitly coordinate their actions through a chat-box that is available for two minutes at the start of each block. To study if subjects properly understood the structure of economic incentives, we ran the NO CM treatment, where we make travel with both goods 2 and 3 suboptimal by altering the BASELINE-R design by setting $c_2 = c_3 = 15$ points.

Finally, in FIAT we add one object, called token, to player 2’s initial endowment in BASELINE. Tokens cannot be produced or consumed, can be stored together with one good, and are costless to transport. This expands the strategy set, allowing fiat monetary trade where tokens circulate from island to island, and goods never move.

To give the best chance to fiat money to arise in the limited session time, we minimized the complexity of this treatment in two ways. Subjects could transport only one object at a time, and in addition to the trade strategies available in BASELINE, they could also either buy their consumption good with a token on a different island, or sell their production good for a token on their own island.

Procedural details: We recruited 513 undergraduate students from Bar Ilan University (approximately 40% males), through class announcements, social media and advertisements on campus. We ran 47 sessions (for details, see the Supplementary Information). The experiment was programmed using the software z-Tree (Fischbacher, 2007). Instructions (see Supplementary Information) were read aloud at the start of the experiment and left on the subjects' desks. All sessions were conducted in the Bar-Ilan University economics experimental lab, where subjects were visually isolated in separate computer carrels. Subjects could not communicate, except in the CHAT sessions. Average earnings per subject were 80 NIS (min = 50 NIS, max = 122 NIS).³ Payments were structured so that subjects could potentially earn similar amounts per round of play in each treatment. In the treatments with type rotation, this was done by summing up all points earned in the session; in the other treatments payments were re-scaled by the maximum points a subject could have earned in the session, given his fixed type (see instructions). Subjects completed between 22 and 66 rounds in a session. Sessions lasted two hours including the reading of instructions, a quiz, and payments.

4 Theoretical considerations

The game described above adapts to the lab the spatially-separated agents model in Goldberg (2007). The setup retains three basic ingredients of standard monetary models: specialized traders, unit storage, and single coincidence in bilateral meetings

³As a comparison, the minimum wage was 24 NIS, and average student wages 30 NIS.

(Kiyotaki and Wright, 1989). It departs from existing theories by not taking bilateral trade as a primitive: multilateral trade is possible in a centralized location.

To develop theoretical predictions, let $j = 1, 2, 3$ denote the player's type, assuming each type is located on their "home" island j , and let $t = 1, 2, \dots$ denote the round. Players specialize in consumption and in production, must trade to consume, and can direct their search to any island. Player j is endowed with one indivisible good of type $j + 1 \pmod{3}$, but derives utility $u > 0$ only from consuming good j . Hence, there is a need for trade. Players can hold just one good as inventory. If they exchange it for their consumption good, they immediately consume and receive a new unit endowment at the start of the following period. Goods can be traded one-for-one but gifts are excluded, hence everyone has some good at the start of every period. Future utility is discounted at rate $\beta \in (0, 1)$.

Players start and end a period on their home island, having the option of making one round-trip to any other island carrying good $k = 1, 2, 3$ at cost $c_k > 0$ for each leg of travel in which they carry a good, with $c_1 < c_2 < u < c_3$. Travel choices are made independently and simultaneously. As a result, a player can be in a *bilateral* or *trilateral* meeting, or meet no-one in the period. In a meeting there is no communication but everyone sees the type and inventory of the counterparts, after which—if players have different inventories—a trade is proposed to all, as follows. In a bilateral meeting players can either exchange their inventories, or do nothing. In a trilateral meeting on island j trade is governed by a direct mechanism. If all goods types are available, then a proposal is made to reallocate goods from producers to consumers; this trilateral exchange is implemented only if there is consensus. Otherwise, or if not all good types are available, player j and the producer of good j are given the option to exchange their goods (if their goods are identical, then player j is offered to trade with the remaining player).

There are generally many equilibria in this game, in which actions may or may not depend on histories of play. We focus on Nash equilibria that are history inde-

pendent (Markov-perfect) because this is the focus of the literature on the micro-foundations of money. Two equilibria seem more natural than others, and have a theoretical counterpart in studies about the endogenous emergence of (de)centralized markets (Camera, 2000; Goldberg, 2007). One has *decentralized* asynchronous trade, as players trade sequentially and bilaterally on different islands; this creates an explicit need for a medium of exchange, for which the low transport cost good 1 is the natural candidate. This dynamic trading arrangement makes consumption infrequent but minimizes the cost of trading, thus granting moderate and similar payoffs to all players. The other has *centralized* synchronous trade, as everyone always congregates on island 2, a natural marketplace where the high transport cost good 3 is produced. This static trading arrangement maximizes the consumption frequency, but makes trade very costly for one player thus creating large disparities in payoffs.

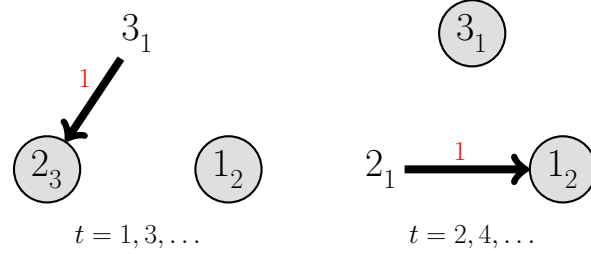


Figure 2: Asynchronous decentralized trade (DM).

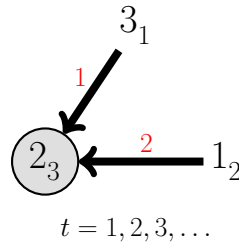


Figure 3: Synchronous centralized trade (CM).

Notes: Players in a circle do not travel. Large number: type and island of player. Small number: player's inventory at start of round. Arrows: direction of travel and good transported.

Fig. 2-3 illustrate the two equilibria. Under decentralized trade, two players al-

ternate travelling with good 1 to bilaterally exchange it for their consumption good. In odd periods player 3 visits and trades with 2, while in even periods 2 visits and trades with 1; player 1 never moves. This trade pattern gives rise to a *decentralized market* (DM) where trade is monetary and bilateral; good 1 serves the role of money as player 2 accepts it to later buy his consumption good. Our design thus makes the transaction role of money explicit. Under centralized trade, the producer of good 3 is visited by the other two. Every period there is a trilateral meeting on island 2, where each player j receives the production of player $j - 1 \pmod{3}$ and gives his to $j + 1 \pmod{3}$. Player 2 never moves. This trade pattern gives rise to a *centralized market* (CM), where trade is non-monetary and multilateral.

Importantly, player 2 “makes a market” in each period by either purchasing a good he cannot consume and then re-trading it (DM), or by facilitating synchronous exchange (CM). Hence, player 2 is pivotal for the emergence or breakdown of equilibrium. In both CM and DM player 2 trades with every other player, and trades in every period, so this player’s deviations are always consequential.

Proposition 1. *In all treatments, except NO CM, both CM and DM are a Nash equilibrium. The equilibrium payoffs to type $i = 1, 2, 3$ in CM are*

$$w_1 = \frac{u - c_2}{1 - \beta} < w_3 = \frac{u - c_1}{1 - \beta} < w_2 = \frac{u}{1 - \beta},$$

while, letting $s = 0, 1$ denote even and odd periods, in DM we have

$$v_1 = \frac{\beta^s u}{1 - \beta^2}, \quad v_2 = \frac{\beta^s (u - c_1)}{1 - \beta^2}, \quad v_3 = \frac{\beta^{1-s} (u - c_1)}{1 - \beta^2}.$$

Proposition 2. *CM is socially efficient but does not Pareto-dominate DM.*

These results are formalized in the Appendix. The first simply requires an analysis of all possible deviations. For the second result, note that given the experimental parameters, the utility increment from maximizing the consumption frequency

through CM dominates the travel cost increment it generates relative to DM. Neither CM nor DM equilibrium is Pareto-dominant because player 1 prefers DM to CM, while the opposite is true for players 2 and 3.

Table 3: Payoffs in the average round, under CM and DM equilibrium.

	Player 1	Player 2	Player 3	Average
CM	2	12	11	8.3
DM	6	5.5	5.5	5.7

Table 3 reveals that in the average round, DM payoffs are rather homogeneous, but CM payoffs are not. When we account for repetition of the game and discounting, this pattern remains. In DM player 2 earns the least as he acts as an intermediary buying and transporting good 1, and consuming with a delay—which is why discounting with β matters. His counterparts either do not travel (player 1), or trade just for their consumption good (player 3), and since transport costs are small their payoff differences are also small. In CM, instead, player 1 earns much less than everyone else because he constantly travels with good 2, which is expensive to carry. As a result, player 1 prefers DM to CM, contrary to his counterparts: players 2 and 3 double their earnings compared to DM because they always consume and have no or tiny travel costs. Hence, though all players benefit from coordinating on some equilibrium, and CM raises average payoffs by more than 40% (last column in Table 3), their incentives are misaligned within a block of play.

Proposition 3. *There are no trade patterns, equilibrium or not, that offer a Pareto-improvement over either CM or DM.*

The assumption $u < c_3$ all but rules out travel with good 3, which is unprofitable. Hence, CM uniquely supports trilateral exchange. It should be clear that since CM maximizes average payoffs, no other bilateral trade pattern (or mix of patterns) exists that Pareto-dominates CM or DM. Indeed, any bilateral exchange

other than DM involves travel with some good other than 1, which raises transport costs but cannot increase consumption frequencies; it simply reallocates travel costs and timing of consumption across players. This implies that *some* player would surely dislike moving away from DM into some other bilateral trade pattern.⁴

Additional considerations: A design with multiple blocks, each with fixed rounds and random termination thereafter, strikes a balance between the desire to facilitate coordination on some equilibrium and to avoid a bias in favor of synchronous one-round exchange. Running multiple rounds in a block facilitates learning to play some equilibrium, but assuming a fixed number of rounds has the drawback of potentially biasing the experiment against a multi-round asynchronous trade pattern because the presence of an approaching final round might cause this trade pattern to unravel (Kovenock and De Vries, 2002). Hence, we use random termination from round six, so that after each round of play subjects anticipate an average of three additional rounds, which is enough to support DM in every round, including round six. This fixed plus random procedure has worked well in related experiments (Bigoni et al., forth.). Running multiple blocks facilitates re-coordination on equilibrium because in each new block we re-initialized the distribution of endowments. To further facilitate coordination subjects could observe the distribution of goods and realized outcomes in their group, and could keep a manual record of outcomes as they were endowed with pencil and paper. If a trade failed in a trilateral meeting subjects were informed about the reason for failure (lack of goods or of mutual consent), though they could not directly observe the trade choices of others.

4.1 Hypotheses

The aim of the experiment is to develop a better understanding of the principles underlying the theory of money, not to reproduce and test a specific monetary

⁴Moving away from CM or DM neither offers a Pareto-improvement (someone is better off and others are not harmed) nor improves average payoffs (some player may be worse off but average surplus increases). Non-equilibrium strategies such as “always trade” cannot raise average payoffs.

model. We thus formulate testable hypotheses when the mapping between theory and design is sufficiently tight, and otherwise conduct a more exploratory analysis.

Based on the considerations expressed above, our working hypothesis is that subjects should coordinate either on DM or on CM equilibrium. Although CM maximizes average payoffs, the incentives are misaligned across players: player 1 earns more under DM, while players 2 and 3 under CM. Hence, there is no obvious reason to expect that an outcome will prevail over the other in the experiment. We thus turn to monetary theory to guide us in formulating a prediction.

As noted earlier, a central idea in that literature is that individuals naturally (and tacitly) coordinate on efficient play. This suggests that monetary exchange should not emerge unless it is “essential” to push forward the efficiency frontier. Although the literature has yet to isolate a set of sufficient conditions for supporting such an essentiality property, a basic ingredient is the assumption of a matching friction that precludes interaction within small groups of fixed counterparts. Put simply, this undermines coordination on non-monetary trading conventions that can improve overall efficiency (Aliprantis et al., 2007). Because this friction is absent in BASELINE, we put forward a first hypothesis:

Hypothesis 1: *In BASELINE, CM emerges and prevails over DM trade.*

In the two REMATCH treatments, we randomly regroup players with each new block, so partnerships periodically break down during the session. In LARGE, we scale up the interaction group beyond three players and randomly allocate travelers to islands of the desired type; here, players meet random counterparts in each round of the session and cannot identify counterparts from previous meetings. These matching frictions not only preclude interaction within a small group of fixed counterparts—albeit to different degrees—but they also impair coordination through tacit means. Empirical evidence suggests that a reason for adopting monetary exchange is that it helps to overcome coordination problems (Camera and Casari, 2014). We thus put forward a second hypothesis:

Hypothesis 2: *The frequency of CM trade declines, and DM rises, with group rematching and random meetings as compared to fixed groups of three players.*

Another theme in the monetary literature is that production specialization encourages monetary exchange, while diversification discourages it. Specialization takes the form of fixed player types who can only produce a single good (Kiyotaki and Wright, 1989), while diversification allows players to increase their production variety at a cost (Camera et al., 2003; Kiyotaki and Wright, 1993). Type rotation is a form of diversification because it relaxes the extreme specialization assumption of fixed types. Yet, rotation does not enable barter, which is unlike what diversification does in models of money. It follows that according to monetary theory rotation should be inconsequential—we should expect CM much as in BASELINE because it is the socially efficient arrangement. However, a distinct mechanism could be operational in our design: individuals care about equality in outcomes (e.g., Bolton and Ockenfels, 2000; Fehr and Schmidt, 1999; Rabin, 1993), a consideration that is absent from standard monetary theory. Table 3 reveals that DM grants similar payoffs in the average round (5.5. vs. 6 points), while CM implies large payoff differences (2 vs. 12 points), which can make DM more attractive with fixed types. Adding rotation can re-align the incentives across players by smoothing out payoff differences over the entire session. Under DM the payoff in the average round of the session is 5.7 points, while it is 8.3 points under CM (see Table 3). If subjects are averse to inequality, then adding type rotation may enhance the attractiveness of CM equilibrium relative to DM. Hence, we formulate a third hypothesis:

Hypothesis 3: *The frequency of CM trade rises, and DM declines, with rotation as opposed to fixed players' types.*

5 Results

We start with an aggregate view, focusing on how subjects planned their meetings in the five main treatments of the experiment, which consist of the BASELINE design

and the four treatment manipulations BASELINE-R, REMATCH, REMATCH-R and LARGE. This is done by studying the combined travel choices in an interaction group, and evaluating their conformity to either CM or DM equilibrium. We then move on to an individual-level analysis of outcomes in meetings.

5.1 Aggregate analysis

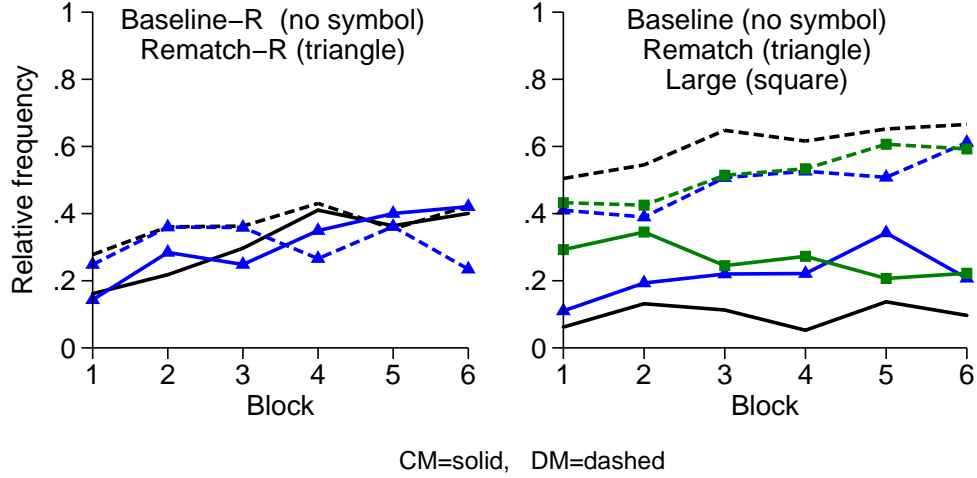
We develop two indicators of equilibrium play, denoted CM and DM , constructed as follows. In a three-player group $CM=1$ in a round if the combined travel choices support a trilateral CM meeting as in Fig. 3, and 0 otherwise; DM is similarly coded following Fig. 2. These values are then averaged across all rounds of a block so both CM and DM range from 0, when no meeting in any round conforms to equilibrium play, to 1 when there is full conformity. Each indicator is aggregated at the economy level, which is the unit of observation in this section.⁵

Result 1. *Overall, CM and DM play organize a majority of the data.*

Fig. 4 shows CM and DM meetings in the average round of a block. In the average block, the value of the sum $CM+DM$ lies between 0.61 and 0.78, suggesting that the theory in Section 4 organizes the data well; the median sum is significantly above 0.50 in every treatment (sign tests, the largest p-value is 0.062). Fig. 4 gives the impression that coordination on equilibrium was not easy, as $CM+DM$ is below 1 in every treatment, even in later blocks. Furthermore, neither CM nor DM appear to drop to zero over time, suggesting a lack of focality except, perhaps, for the BASELINE treatment. This supports our working hypothesis.

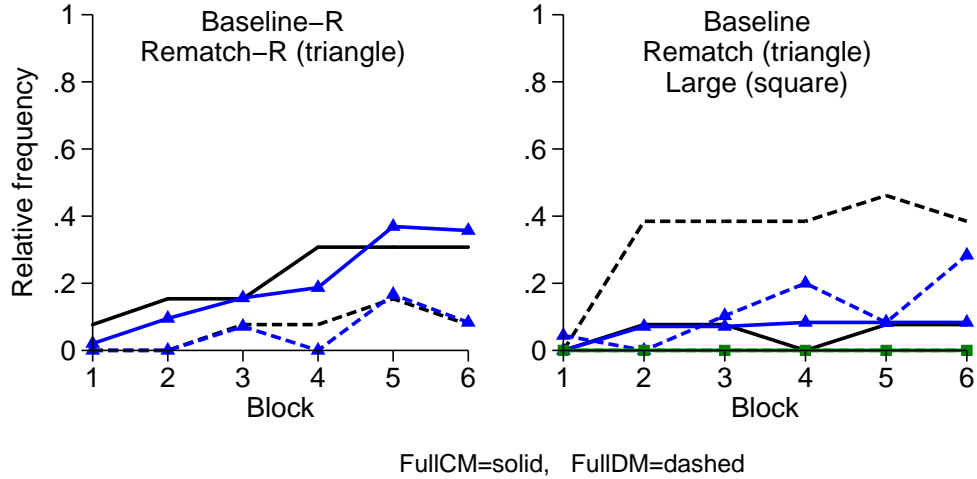
⁵In LARGE, CM and DM measure the maximum fraction of CM and DM meetings possible in the round (realized meetings may be less, due to the random allocation of players). In rematching treatments, we average CM and DM across the economy's groups. The Supplementary Information provides details on these calculations; Fig. A.1 shows the frequency of other possible meeting patterns, and reveals that travel between islands 1 and 3, and travel with good 3 is negligible.

Figure 4: Coordination on CM and DM meetings in the average round.



Notes: One obs.=one economy in a block (N=13 in each block for BASELINE and BASELINE-R; N=7 in blocks 1-3 and N=6 in blocks 4-6 for REMATCH; N=7 in blocks 1-4 and N=6 in blocks 5-6 in REMATCH-R; N=9,8,8,5,4,3 in blocks 1-6 in LARGE). *CM* = relative frequency of coordination on CM meetings in a round; *DM* = relative frequency of coordination on DM meetings in a round.

Figure 5: Coordination on CM and DM meetings in an entire block.



Notes: One obs.=one economy in a block. *FullCM* = share of groups within the economy that coordinated on CM meetings in every round of the block; *FullDM* = share of groups within the economy that coordinated on DM meetings in every round of the block.

A more stringent way to assess coordination on equilibrium is to measure how

frequently an economy coordinated on some equilibrium *in an entire block*. Fig. 5 displays behavior in line with either equilibrium for an entire block. In a three-player group $FullCM=1$ in a block if the combined travel choices support trilateral CM meetings in every round of the block, and 0 otherwise; $FullDM$ is coded accordingly. Coordination on an equilibrium for the entire block is clearly much more challenging. None of the LARGE economies coordinated on an equilibrium in the entire block. In the remaining treatments, in the average block the sum of values $FullCM+FullDM$ lies between 0.18 and 0.38. Again we see a lack of focality of either equilibrium, except for the BASELINE treatment.

Result 2. *In BASELINE, DM trade prevailed over CM trade from the beginning of the session.*

Fig. 4 and Table 4 provide support. BASELINE exhibits the smallest frequency of CM meetings, and the largest frequency of DM meetings of all treatments. Subjects coordinated on DM equilibrium from the beginning of the session, and the frequency of DM play increased as subjects gained experience with the task. Conversely, CM equilibrium play is infrequent and does not increase with experience (see Fig. 4, right panel). Decentralized monetary trade prevailed over centralized trade; overall, the mean values of CM and DM are 0.10 and 0.61, a significant difference ($p\text{-value}<0.001$, $N1=N2=13$).⁶ Based on this evidence, Hypothesis 1 is rejected.

As we have few independent observations, we also ran panel regressions using an economy in a block as the unit of observation; these offer additional supporting evidence for Result 2. The panel structure is suitable in our case because one economy gives rise to an independent sequence of observations. As we pooled data from all main treatments, we use a categorical variable to estimate treatment effects, with BASELINE corresponding to the base of the regression. We also include a

⁶Unless otherwise noted, all statistical tests in this section use an economy as the unit of observation (No. of obs. in notes to Fig. 4 and in Table A.1 in the Supplementary Information) and two-sided Wilcoxon-Mann Whitney ranksum tests with exact statistics.

continuous *Block* regressor interacted with the treatment variables to determine how experience with the task affected behavior across the various treatments. A set of additional controls soaks up the effect of economy size, gender composition, and duration of the block—current and previous.

In column 1 of Table 4 the dependent variable is the frequency of CM. The intercept is close to and statistically indistinguishable from zero. Instead in column 2, where DM is the dependent variable, the intercept term is positive and highly significant. This is evidence that subjects initially coordinated on DM equilibrium and not on CM. The estimated coefficients of the learning covariates indicate that in BASELINE subjects learned to play DM equilibrium as they gained experience with the task; the coefficient on the *Block* regressor is positive and significant in (2) and insignificant in (1). Again, this allows us to reject Hypothesis 1.

The prevalence of DM trade is also observed when we manipulate the baseline design by introducing matching frictions. However, when production types rotate we find that CM trade partially crowded out DM trade.

Result 3. *Subjects learned to coordinate on some equilibrium: CM with type rotation, and DM otherwise.*

Fig. 4-5 and the panel regressions in Table 4 offer evidence. Using Fig. 4 to visually compare the treatment manipulations to the fixed three-person group design of BASELINE suggests two considerations. First, adding matching frictions does not alter the prevalence of DM trade, although DM declines and CM increases, especially initially in LARGE (right panel). In REMATCH and LARGE, the mean values are $CM=0.20, 0.27$ and $DM=0.50, 0.51$, respectively; we can reject the hypothesis that *DM* and *CM* are statistically similar (p-values 0.07 and 0.010, respectively). Second, trade patterns shifted from DM monetary to CM non-monetary trade when we added type rotation, although neither equilibrium seems to prevail (left panel). Overall, the treatments with type rotation, BASELINE-R and REMATCH-R, exhibit the largest

average frequency of CM meetings, 0.31 and 0.30, and about half as much DM meetings as compared to BASELINE, 0.37 and 0.31; within each treatment with type rotation we cannot reject the hypothesis that *CM* and *DM* are statistically similar, suggesting that neither equilibrium was particularly salient.

Considering cross-treatment comparisons, we can reject the hypothesis that *CM* is statistically similar in BASELINE and any of the other treatments (5% level or better). We can also reject the hypothesis that *DM* is statistically similar in REMATCH-R as compared to REMATCH and LARGE (10% level or better). No other treatment comparison reveals a significant difference. This is an initial indication that trade patterns shifted from decentralized to centralized markets when we added type rotation; hence, Hypothesis 3 cannot be rejected. Moreover there is also evidence that the random re-matching friction in LARGE led to more CM trade (but similar DM trade) as compared to BASELINE, while the differences between BASELINE and REMATCH are insignificant; hence, Hypothesis 2 can be rejected.

To assess how the treatment manipulations affected initial vs. long-run play, consider the regressions in Table 4. The intercept terms allow us to assess treatment effects of play of inexperienced subjects. Introducing rematching or type rotation caused an initial shift away from DM towards CM trade as compared to BASELINE; in column 2, all coefficients on the treatment dummies are negative and significant (Wald tests reveal that they are statistically similar), while in column 1, all coefficients on the treatment dummies are positive, although only LARGE is significant. Again, this is in contrast with Hypothesis 2.

Yet, the estimated coefficients of the learning covariates indicate that this effect is short-lived in all treatments with fixed types: as subjects gained experience with the task, they learned to play DM equilibrium much as it happens in BASELINE. Periodically breaking up partnerships through random re-matching in each block did not alter the learning trend observed in BASELINE (the coefficients on *Rematch* \times *Block* are insignificant), while constant random re-matching strengthened

it (the coefficient on $Large \times Block$ is positive and significant in (2)).⁷

Table 4: CM and DM meetings and efficiency: panel regression

Dep. var.	(1) <i>CM</i>		(2) <i>DM</i>		(3) <i>Efficiency</i>	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
<i>Treatment</i>						
Baseline-R	0.058	(0.063)	-0.199**	(0.083)	-0.245	(0.196)
Rematch	0.079	(0.074)	-0.204**	(0.099)	-0.208	(0.156)
Rematch-R	0.073	(0.057)	-0.230**	(0.103)	-0.175	(0.127)
Large	0.268***	(0.067)	-0.203*	(0.106)	-0.096	(0.153)
<i>Learning covariates</i>						
Block	0.008	(0.012)	0.030***	(0.006)	0.067***	(0.010)
Baseline-R \times Block	0.040*	(0.022)	-0.009	(0.017)	0.056	(0.038)
Rematch \times Block	0.011	(0.025)	0.018	(0.017)	0.020	(0.022)
Rematch-R \times Block	0.041*	(0.023)	-0.030**	(0.013)	0.021	(0.020)
Large \times Block	-0.023	(0.021)	0.016**	(0.007)	-0.016	(0.018)
Economy size	-0.006	(0.034)	0.049	(0.034)	0.058*	(0.035)
Constant	0.066	(0.042)	0.538***	(0.085)	0.218**	(0.103)
Controls	Yes		Yes		Yes	
N	272		272		272	
R ² within	0.105		0.095		0.262	
R ² between	0.160		0.170		0.084	
R ² overall	0.133		0.153		0.186	

Notes: Panel regressions with random effects. One observation = one economy in a block. *CM* = relative frequency of coordination on CM meetings in the average round of the block; *DM* = relative frequency of coordination on DM meetings in the average round of the block. *Efficiency* = per-capita profit in the average round of the block, divided by the maximum per-capita profit (the profit from CM trade). *Controls* include standardized measures of block duration, current and previous (set to 9 rounds, in block 1), and gender composition in the economy (self-reported). Robust standard errors (S.E.) adjusted for clustering at the session level. Symbols ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

Instead, with type rotation, subjects learned to play CM. The coefficients on *Baseline-R \times Block* and *Rematch-R \times Block* are positive and significant in (1); they are similar (Wald test), suggesting that rematching by itself did not diminish the impact of rotation on learning to play CM equilibrium. Neither *Baseline-R \times Block*

⁷In all treatments there is a significant upward trend in equilibrium play, CM or DM, also evidence of convergence to an equilibrium. Evidence comes from a panel regression where the dependent variable is the sum $CM + DM$. In Table A.2 in Supplementary Information, the coefficient on the *Block* regressor is positive and highly significant; we can reject the hypothesis that $Block + treatment \times Block = 0$ in all other treatment manipulations.

nor the sum of $Block + Rematch-R \times Block$ are different than zero in (2). Because subjects benefit from learning to coordinate on some equilibrium, we also see that individual payoffs and, therefore, efficiency grow over time in all treatments. This is seen in column (3) of Table 4 (Wald tests reveal that the sum of $Block$ and the relevant interaction covariate is significantly different than zero for each treatment).⁸

The evidence that introducing type rotation instead of fixed types caused a shift from DM to CM trade is clearly in line with Hypothesis 3. However, the observation that when we added a random rematching friction DM initially declined is in contrast with Hypothesis 2. Again, a more stringent way to assess coordination on equilibrium in the various treatments is to measure how frequently an economy coordinated on some equilibrium *in an entire block*. Data are reported in Fig. 5. Three observations stand out. First, coordination in an entire block is most frequently attained in BASELINE, followed by the rotation treatments and REMATCH, while it is never observed in large groups. This pattern is intuitive considering that the environment becomes progressively less stable: we go from small groups of partners and fixed roles (baseline), to one where roles switch in each block (rotation), to one in which counterparts switch in each block (rematching), to one with many counterparts that switch in each round (large). Second, in treatments with three-person groups the lines in Fig. 5 exhibit a positive trend, suggesting that as subjects gained experience with the task, they learned to coordinate on an equilibrium for the entire block. Third, $FullDM$ increases over time in BASELINE, and $FullCM$ in rotation treatments, suggesting that if an equilibrium was attained in a block, then it remained stable; the pattern is less clear in REMATCH.⁹

⁸Realized efficiency is the aggregate payoff observed in an economy, divided by the maximum theoretical payoff (the CM payoff). The efficiency in block 1 was .22, -.06, .04, -.02, .18, and it increased to .54, .65, .51, .51, .50 in block 6 for, respectively, BASELINE, BASELINE-R, REMATCH, REMATCH-R and LARGE. See Fig. A.2 in the Supplementary Information.

⁹We ran two-sided Wilcoxon-Mann Whitney ranksum test with exact statistics. The independent unit of observation is the frequency of coordination on CM and DM in all periods of the block, in the average group of an economy, in a session. $FullCM$ and $FullDM$ are significantly different in BASELINE (p-value=0.027, N1=N2=13), BASELINE-R (p-value=0.078, N1=N2=13) and

Summing up: subjects learned to coordinate either on CM or DM equilibrium in the experiment. DM prevailed over socially efficient CM in all treatments with fixed types; with type rotation centralized non-monetary trade emerged and crowded out decentralized monetary trade. This last observation is consistent with the predictions of standard monetary theory—CM should emerge because it is socially efficient—but the former is not. The fact that monetary trade emerged in the frictionless baseline design is in contrast with the theory; the initial decline in DM trade when we added meeting frictions is also unexpected. Yet, the prevalence of monetary trade is consistent with possible concerns about equality in outcomes—a consideration that is absent from monetary theory. The large payoff differences of CM trade may become acceptable when players anticipate that rotation will smooth these differences out over the course of the session. To sharpen this aggregate analysis of meeting choices, we study outcomes for the pivotal player 2, who is the only one who in every equilibrium trades in every round, and trades with everyone else.

5.2 Individual-level analysis

To start, we consider what good players 2 acquired when they traded. This provides direct evidence about the organization of trade, which complements the indirect evidence from analysis of planned meetings at the aggregate level.

Result 4. *In treatments with fixed types, player 2 more frequently traded his production good for good 1 than good 2, but switched to trading for good 2 when types rotated.*

Evidence comes from the multinomial logit regression in Table 5. One observation is one player 2 in a round in which trilateral and bilateral trade were both feasible, unconditional on travel decisions. This means that all three good types must be available in the interaction group, so DM and CM equilibrium are both fea-

REMATCH-R (p-value=0.036, N1=N2=7), but not REMATCH (p-value=0.323, N1=N2=7).

sible in the round. Given this feasibility requirement, the outcome depends on the travel and trading choices of all players. For example, CM is enabled only if player 1 chooses to visit island 2. The outcome variable takes one of three possible values associated with the mutually exclusive cases of “no trade” (0), “trades for good 1” (1) and “trades for good 2” (2). We separately consider the initial three and the last three blocks to isolate the treatment effect on play of (in)experienced subjects. We include treatment dummies that are interacted with the block regressor, and standard controls. The dummy *Random termination* soaks up the effect of random termination starting in round 6. Finally, since in LARGE we scale up the group, the continuous variable *CM feasibility* captures the number of trilateral exchanges that are feasible, based on the goods available overall in the group (ranging from 1, if everyone has their production good, to 0, if some good type is missing).

In BASELINE the estimated probabilities that player 2 does not trade are .22 (blocks 1-3) and .23 (blocks 4-6); the probabilities that she bilaterally trades her production (good 3) for the medium of exchange (good 1) are .57 and .53; and she trilaterally trades and gets her consumption good 2 with probabilities .21 and .24. This corroborates the earlier evidence that DM is prevalent in BASELINE.

Rematching did not alter this pattern. The marginal effects of *Rematch* on the probabilities of trading for good 1 or 2 are insignificant. The scaling up of groups and random rematching introduced in LARGE initially significantly decreased the frequency of DM trade relative to BASELINE, while raising CM and the incidence of trade; however, there are no significant differences later in the session (see the coefficient on *Large*). This evidence is again in contrast with Hypothesis 2. Conversely, type rotation led to the emergence of centralized markets and coordination on CM trade. In blocks 4-6, the coefficients on the *Baseline-R* and *Rematch-R* dummies reveal that the probability of engaging in CM trade increased by 43 and 36 percentage points, respectively, relative to BASELINE; the coefficients are significant and similarly large (Wald tests). This is evidence that adding rotation increased CM

trade, even if we added rematching; this is in line with Hypothesis 3.

Table 5: Outcomes for player 2: marginal effects

Good traded	(1) Blocks 1-3			(2) Blocks 4-6		
	none	1	2	none	1	2
<i>Treatments</i>						
Baseline-R	0.147** (0.074)	-0.332*** (0.087)	0.185* (0.108)	-0.094 (0.125)	-0.335*** (0.077)	0.429*** (0.150)
Rematch	0.227** (0.103)	-0.212 (0.139)	-0.015 (0.099)	0.081 (0.149)	-0.153 (0.155)	0.072 (0.171)
Rematch-R	0.128* (0.067)	-0.360*** (0.101)	0.232** (0.097)	-0.019 (0.119)	-0.338*** (0.130)	0.357** (0.180)
Large	0.216** (0.086)	-0.418*** (0.106)	0.202** (0.095)	0.018 (0.139)	-0.123 (0.130)	0.104 (0.161)
Block	-0.068*** (0.018)	0.035 (0.047)	0.034 (0.046)	-0.043 (0.028)	0.025** (0.012)	0.019 (0.025)
Rand. Term.	-0.018 (0.017)	0.008 (0.023)	0.010 (0.016)	0.004 (0.026)	-0.001 (0.030)	-0.003 (0.024)
CM Feas.	0.171 (0.107)	-0.026 (0.238)	-0.145 (0.162)	0.095 (0.179)	0.368 (0.231)	-0.463 (0.293)
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Multinomial logit regressions on the three outcomes for player 2: 0 (does not trade), 1 (trades for good 1), and 2 (trades for good 2). One obs. = player 2 in a round (N=2654 for blocks 1-3 and N=1478 for blocks 4-6). Only rounds in which both CM and DM are feasible. *CM feasibility* is 1 in all three-player groups, while in LARGE where the interaction group is a multiple of three, it measures the maximum number of trilateral meetings that can be formed, given the available goods. *Random termination* = 1 for rounds 6 and above (0, otherwise). *Controls* include the size of the economy, and gender composition in the economy (self-reported). Robust standard errors (S.E.) adjusted for clustering at the session level. Symbols ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

From a more exploratory perspective, the regression also provides individual-level evidence about coordination on equilibrium. Theoretically, player 2 should trade in all rounds, in both CM and DM, and in all treatments. While this is not what we observe, we do find that trade is frequent and increases with experience.¹⁰ This corroborates the earlier finding that subjects learned to play some equilibrium

¹⁰The probabilities that player 2 trades in a round (not necessarily an equilibrium trade) in BASELINE, BASELINE-R, REMATCH, REMATCH-R and LARGE are, respectively, .69, .51, .58, .58, and .66 in blocks 1-3, and they all increase to .80, .77, .68, .71 and .83 in blocks 4-6.

over the course of the session. Moving away from groups of three partners with fixed roles, however, increased coordination difficulties (the treatment dummies for the “no trade” outcome are all positive and significant in blocks 1-3) and created instability in trading choices.

Result 5. *Equilibrium is more stable in BASELINE than in all other treatments.*

A group coordinates on CM (DM) equilibrium in a round, if player 2 trilaterally (bilaterally) trades in conformity with CM (DM). Hence, to investigate stability of equilibrium across treatments we study the frequency distribution of equilibrium breakdowns experienced by player 2, reported in Table 6. Overall, equilibrium classifies about 2/3 of player 2’s outcomes. An equilibrium breaks down when it is observed in round t but not in $t+1$; the frequencies of breakdowns are in parentheses.

Table 6: Equilibrium play and breakdowns in a round

	CM trade	DM trade	Other	N
Baseline	69 (14)	427 (27)	210	706
Baseline-R	206 (16)	182 (44)	245	633
Rematch	125 (32)	471 (98)	471	1067
Rematch-R	313 (29)	295 (82)	433	1041
Large	453 (253)	748 (197)	613	1814

Notes: One observation = player 2 in a round. CM (DM) trade = player 2 engages in CM (DM) trade; Other = player 2 neither attained CM nor DM trade; N= number of obs.. In parentheses the frequency of equilibrium breakdowns in the subsequent round.

The first logit regression in Table 7 tests for stability differentials across treatments by considering data from all rounds that followed either CM or DM equilibrium play. The dependent variable takes value 1 if the equilibrium broke down, and 0 otherwise. The coefficients on the treatment dummies are all positive and significant. Moreover, the coefficient on *Large* is significantly bigger than all others

(Wald tests, p-values at or above 5% level), while all other treatment coefficients are statistically similar (Wald tests).

Table 7: Equilibrium breakdowns and trade failures: marginal effects

<i>Dep Var. = 1 if:</i>	<i>(1) Eq'm breakdown</i>		<i>(2) 2 avoids DM trade</i>	
	Coeff.	S.E.	Coeff.	S.E.
<i>Treatments</i>				
Baseline-R	0.099*	(0.058)	0.198***	(0.054)
Rematch	0.178***	(0.058)	0.227***	(0.080)
Rematch-R	0.131***	(0.039)	0.215***	(0.082)
Large	0.334***	(0.056)	0.213**	(0.093)
Block	-0.029*	(0.017)	-0.008	(0.013)
Random termination	-0.025**	(0.012)	-0.014	(0.011)
Controls	Yes		Yes	
N	2936		3267	

Notes: Logit regressions. One obs. = player 2 in one round. Left regression: Dep. var. = 1 if the equilibrium broke down (else, 0); includes only rounds following equilibrium play. Right regression: dep. var. = 1 if there is no DM trade (else, 0); includes only rounds in which player 2 is either in a DM meeting with 3, or holds good 1. *Random termination* = 1 for rounds 6 and above (0, otherwise). *Controls* include size of the economy, and gender (self-reported). Robust standard errors (S.E.) adjusted for clustering at the session level. Symbols ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

It is not surprising that breakdowns are more common in large groups, partly due to involuntary failures (random meetings).¹¹ But what explains the breakdowns with rematching and rotation? Apart from error, breakdowns may stem from players' conflicting incentives: DM offers better prospects to player 1, who may push for it by avoiding island 2. In fact, player 1 is the one who selects which equilibrium the group can achieve; by avoiding island 2 she prevents CM equilibrium. But "assertive" players 2 may signal their commitment to CM, by either refusing good

¹¹If we augment the notion of stability by considering transitions from one block to the next, instead of one round to the next, we have a similar picture. Full coordination never occurred in large groups, BASELINE exhibits the greatest coordination (on DM), which is also quite stable. Miscoordination was especially common under rematching and rotation.

1 or refusing to travel with it. Players 2 can easily develop a reputation for being assertive in small groups of fixed partners, but not so easily if types rotate, and especially if counterparts randomly change across blocks or rounds. In this case, the player must repeatedly derail a monetary trade to signal his “type.” If so, DM trades should fail less in BASELINE than in other treatments.

The data confirm the intuition about the source of trade failures. Consider all observations while excluding those from LARGE where trade failures are also caused by random allocation to islands. Player 2 held good 3 in 2503 rounds and good 1 in 944 rounds. When player 2 held his own production, player 1 visited island 2 only 33% of times, vs. 77% for player 3. Player 1 is thus the main cause of CM breakdowns. There are 91 cases of CM breakdowns: in 84 of these player 1 did not visit island 2. Player 2 often took this deviation in stride, bilaterally trading with player 3 in about half of the cases. However, player 2 was also assertive in signaling a desire for CM. There are 251 cases of DM breakdowns: in 159 of these player 2 held good 1 and in the others good 3. Conditional on holding good 1, player 2 refused to visit island 1 in 60% of cases. Conditional on holding good 3 and meeting type 3, player 2 refused to trade in about 36% of cases (N=49).

We also find that players 2 were the least likely to derail a DM trade in BASELINE. The second regression in Table 7, considers all rounds in which player 2 had the opportunity to complete a DM trade; the dependent variable takes value 1 if player 2 derailed the trade (0 otherwise). The coefficients on the treatment dummies are all positive and significant, which helps explain why making interactions impersonal through rematching and random meetings frictions failed to boost DM as predicted by the monetary literature: these manipulations reinforced coordination problems among players whose incentives were already misaligned.

But if this is the explanation, why did rotation—which also increased coordination frictions—lead to the emergence of centralized markets, even when we randomly rematched subjects? And why did the baseline setup without matching frictions con-

verge to DM trade instead of to the socially efficient CM trade as monetary theory would suggest? Finally, how would the organization of trade be affected in the presence of bilateral barter or bilateral fiat monetary exchange? We tackle these questions through four additional treatments.¹²

5.3 Four additional treatments

Given the results of the main treatments, we carry out an exploratory analysis about the role of strategic uncertainty, of payoff inequality, and the effect of competition with barter and fiat monetary exchange.

We start by expanding upon Result 1, which is in contrast with Hypothesis 1. Aversion to inequality is a possible explanation. In the average round DM grants similar payoffs (6, 5.5 and 5.5 points) while CM does not (2, 12 and 11 points). Inequality-averse subjects would naturally focus on DM, and avoid CM. Strategic uncertainty is another possible reason for the dominance of DM in BASELINE; with fixed types, players' incentives are conflicting and individuals might be uncertain what equilibrium others will choose. This especially matters to player 1, who earns a meager payoff under CM and might wish to “push” for DM by avoiding island 2. This choice is risky as player 1 foregoes a trilateral trade, but player 2 may refuse to accept good 1. We show that player 1 would want to take this kind of risk.

The role of strategic uncertainty. Given that our game is asymmetric, does not have a two-by-two structure, and admits more than two equilibria we consider a notion of risk dominance that departs from the formalization in Harsanyi and Selten (1988), but conforms to the heuristic argument that motivates it.¹³ In particular, we focus on player 1 because she selects which equilibrium the group can achieve;

¹²We thank anonymous referees for suggesting an extended line of inquiry.

¹³It is close to the formulation in Haruvy and Stahl (2004) and Fehr et al. (2018) where the risk-dominant equilibrium maximizes the expected payoff when players have uniformly distributed second order beliefs on all equilibria. Bigoni et al. (forth.) consider a reduced game with only two equilibria (efficient and inefficient) that players believe others select with equal probability.

by avoiding island 2, she precludes CM equilibrium. The problem is that she is uncertain what strategy player 2 will select. We assume that player 1 believes that player 2 is equally likely to select either CM or DM, and believes that player 2 has similar beliefs about her own strategy selection. To develop the argument, note that there is neither uncertainty over the initial travel choices of players 2 and 3 (in both equilibria they choose island 2) nor the trade choice of player 3 (she only accepts good 3 in both equilibria). The uncertainty is all about player 2's choice: will she accept good 1? Suppose player 1 believes this to be a coin toss (principle of insufficient reason). Her dilemma is: travel to island 2 to coordinate on CM, or stay home and see if player 2 accepts good 1. At the end of the round, the uncertainty is resolved, so players can coordinate on DM if good 1 is traded, and on CM otherwise. We say that DM is risk dominant for player 1 if it delivers a greater expected payoff than the payoff earned from choosing CM, which is $w_1 = \frac{u - c_2}{1 - \beta}$. Given this notion of risk-dominance we have the following result:

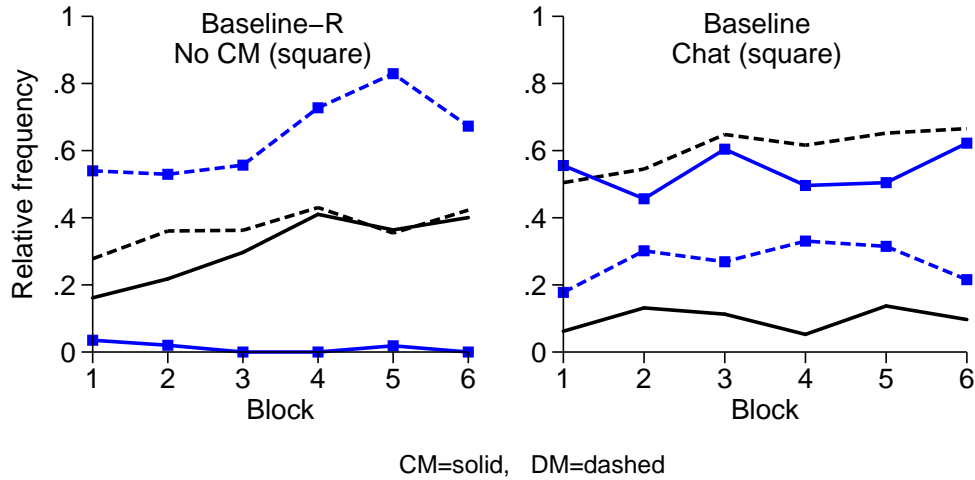
Proposition 4. *In BASELINE, DM is risk-dominant.*

The expected payoff to player 1 from staying home is $\frac{1}{2}v_1 + \frac{1}{2}\beta w_1$ where $v_1 = \frac{\beta u}{1 - \beta^2}$ is the equilibrium payoff in the initial round of DM trade. Player 1 neither consumes nor produces, and expects CM or DM with equal probability from next round. Given the parameterization in BASELINE we have $w_1 < \frac{1}{2}v_1 + \frac{1}{2}\beta w_1$.

Two of three players prefer CM to DM trade. If strategic uncertainty is what supports DM trade, adding a coordination-enhancing institution should cause a shift from DM to CM trade since all players benefit from avoiding mis-coordination. To test this hypothesis we ran the CHAT treatment, which adds costless pre-play free-form communication at the start of each block of BASELINE. This allows us to investigate the role of coordination frictions because it neither removes equilibria, nor resolves the problem of conflicting incentives. Adding pre-play communication can mitigate strategic uncertainty since subjects can coordinate their actions.

The right hand side of Fig. 6 reports the frequency of CM and DM in the average economy of BASELINE vs. CHAT. There is a sharp equilibrium reversal, supporting the view that strategic uncertainty played a role in the adoption of DM. CM trade jumped from 0.10 to 0.54, while DM trade sharply declined from 0.61 to 0.27; both differences are significant (two sided Wilcoxon-Mann Whitney ranksum test with exact statistics; for CM, p-value=0.004, N1=13, N2=12; for DM p-value=0.012, N1=13, N2=12). A regression similar to the one in Table 5 confirms the significance of these non-parametric results (see Table A.3 in Supplementary Information).

Figure 6: The CHAT and NO CM vs. BASELINE and BASELINE-R treatments



Notes: One obs.=one economy in a block (N=13 in each block for BASELINE and BASELINE-R; N=12 in each block for CHAT; N=9 in each block for NO CM). *CM* = frequency of CM meetings; *DM* = frequency of DM meetings.

It is also conceivable that pre-play communication affected inequality concerns, reducing subjects' inclination to seek DM as a way to attain more balanced payoffs. Indeed, we have seen that by adding rotation to the frictionless BASELINE treatment, CM emerged and crowded out DM trade. We discuss this next.

The role of the payoffs distribution. In treatments with type rotation everyone experiences each role twice in the session. This removes the large payoff

differences of CM trade if players coordinate on CM in the entire session; the payoff in the average round of the session is simply the payoff of the average player. This average is 45% larger under CM than DM (see Table 3). Rotation can thus make CM more attractive because it re-aligns the incentives across players dynamically, by equalizing the distribution of payoffs over the entire session. This, we argued in Section 4.1, is a further reason why CM might emerge under rotation but not under fixed types. We tested this hypothesis through a logit regression similar to the one reported in the previous section, focusing on the initial travel decisions of players 1 (round 1 in a block). If rotation enhances the attractiveness of CM relative to DM, then it should remove the incentive for player 1 to push for DM in that first round. If so, then we should observe more travel from the get go—even when we add a rematching friction. Indeed, there is a statistically significant increase in the probability of travel in BASELINE-R as compared to BASELINE, and in REMATCHING-R vs. REMATCHING (see Table A.4 in Supplementary Information).

An alternative hypothesis is that rotation supported CM simply because subjects *misunderstood* the structure of economic incentives—switching types might have confused them. For example, subjects sought outcomes that maximize the sum of payoffs in the entire session, even if some player could personally gain from acting differently than that outcome. To assess this possibility we modified the BASELINE-R design—where subjects learned to coordinate on CM trade—removing CM from the equilibrium set. The NO CM treatment raises the cost c_2 from 10 to 15 points, on par with c_3 . Here *any* trilateral trade is unprofitable for at least one player; in particular, player 1 has a 3 points loss under CM, although CM ensures 7 points to the average player, which is 1.3 points above the average payoff in DM (which remains an equilibrium). If rotation alters subjects’ understanding of the economic incentives, then we should still observe some trilateral trades. The left hand side of Fig. 6 reports the frequency of CM and DM in BASELINE-R vs. NO CM for an economy. The average CM significantly drops from 0.31 to 0.01, while

DM trade significantly rises from 0.37 to 0.64 (two sided Wilcoxon-Mann Whitney ranksum test with exact statistics; for CM p-value=0.004, N1=13, N2=9; for DM p-value=0.014, N1=13, N2=9).¹⁴ We summarize these findings as follows.

Result 6. *Introducing costless pre-play communication caused a shift from DM to CM trade. Adding rotation induced player 1 to more frequently enable CM at the start of the game. Raising c_2 to c_3 caused a shift from CM to DM trade.*

The role of barter. The monetary literature emphasizes that decentralized monetary exchange spontaneously emerges as an optimal response to the inefficiency of diversification and barter trade, and the impossibility of centralized exchange (Camera et al., 2003). Earlier, we added type rotation as a way to relax the extreme form of specialization typical of monetary models, and argued that this alternation in economic tasks re-aligns the incentives across players thus explaining Result 3. Though rotation can be seen as a form of diversification (less specialization), this explanation is distinct from the usual one in monetary theory for why diversification weakens DM. There, diversification enables barter, while in our rotation treatments it does not. To investigate the role of barter on the endogenous organization of trade, we thus introduce the possibility to diversify production and then barter it. Adding this option expands the equilibrium set because it supports barter equilibria that, however, are not socially efficient.¹⁵ Here, centralized market trading should still emerge because it still is socially efficient.

To test this intuition, we manipulate the BASELINE-R design—where play converged to CM—by allowing double coincidence meetings. In this BARTER treatment, players can pay 2 points to produce the other good they cannot consume, instead of their specialty good. If everyone produces their specialty good, then the probability

¹⁴One of the three NO CM sessions was run without rotation to explore possible effects, but there are none—these results hold without that session included.

¹⁵In models of money, bartering own production is simply unfeasible (Kiyotaki and Wright, 1989). Conditional on being feasible, then barter equilibrium would be efficient, but not necessarily if enabling barter is costly (Camera et al., 2003).

of double coincidence is zero as in the original design. Otherwise, two producers can barter, and three barter equilibria may arise. Under low-cost barter, player 2 produces good 1 (instead of 3) and barter it for 2 on island 1, so player 3 remains idle. In another low-cost barter equilibrium, player 1 produces good 3 (instead of 2) and barter it on island 1 for good 1, so player 2 never trades. In a high-cost barter equilibrium, player 3 produces good 2 (instead of 1) and barter it for good 3 on island 2, so player 1 never trades (see Fig. A.3 in Supplementary Information).

If barter occurs, then the distribution of payoffs across players is even more unequal than under CM, since one player type does not consume. However, types rotate from block to block in BARTER, which smooths out the large payoff differences of barter equilibrium over the entire session. For the low-cost and high-cost barter equilibria, the expected payoffs in the average round of the session are, respectively,

$$w_L^B = \frac{2u - c_1 - 2}{3(1 - \beta)}, \quad \text{and} \quad w_H^B = \frac{2u - c_2 - 2}{3(1 - \beta)}.$$

CM and DM are still equilibria, and there is an explicit tradeoff between barter, monetary trade, and centralized trade. DM generates smaller expected session payoffs than low-cost barter, and higher expected payoffs than high-cost barter. CM is still socially efficient, i.e., $w > w_L^B > v > w_H^B$.¹⁶ Hence, though barter might replace DM, according to the insights from the monetary literature, barter should not crowd-out CM. Moreover, rotation also ensures equalization of the distribution of CM payoffs over the entire session. In fact, the data reveal something different.

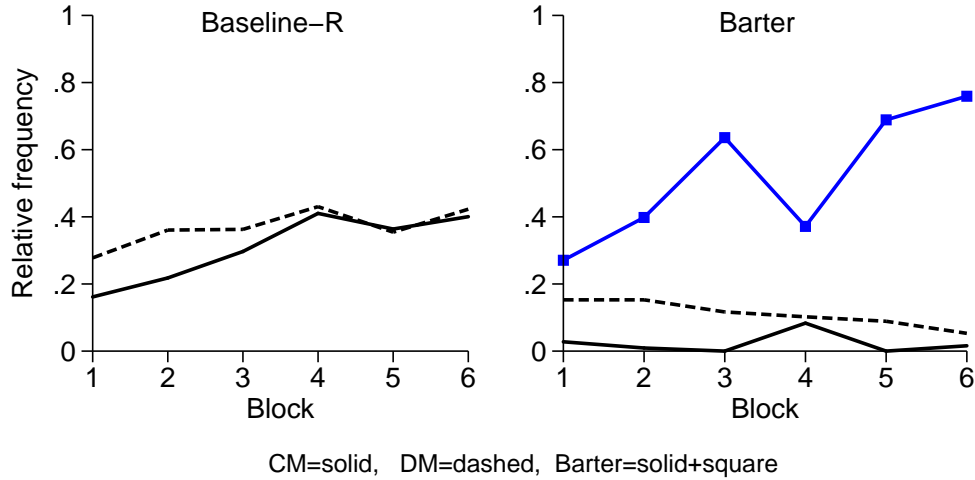
Result 7. *The ability to adjust production and seek double coincidence meetings gave rise to inefficient barter equilibria, which crowded out both CM and DM trade.*

Fig. 7 shows that barter increased over time, DM declined, and CM was rare. Considering the average economy in BASELINE-R vs. BARTER, the relative fre-

¹⁶The (normalized) expected CM payoff $(1 - \beta)w = 8.3$, the low-cost barter payoff is $(1 - \beta)w_L^B = 7$ and the high-cost barter payoff is $(1 - \beta)w_H^B = 4$.

quency of CM dropped from 0.31 to 0.02, while DM fell from 0.37 to 0.11; both differences are statistically significant (two sided Wilcoxon-Mann Whitney ranksum test with exact statistics; CM, p-value=0.002, N1=13, N2=12; DM, p-value=0.004, N1=13, N2=12). By contrast the frequency of barter is 0.52.¹⁷ Of all barter trades, only 4% were high-cost, while most (60%) involved players 1 and 2. As a result, player 1 traded and consumed significantly more than in BASELINE-R (Table A.5, Supplementary Information). This reallocation of trade activity redistributed profit away from player 3 to players 1 and 2 (panel regressions, data not reported).

Figure 7: BARTER vs. BASELINE-R



Notes: One obs.=one economy in a block (N=13 in each block for BASELINE-R; N=12 in each block for BARTER). *CM* = frequency of CM meetings; *DM* = frequency of DM meetings. *Barter*: frequency of barter meetings.

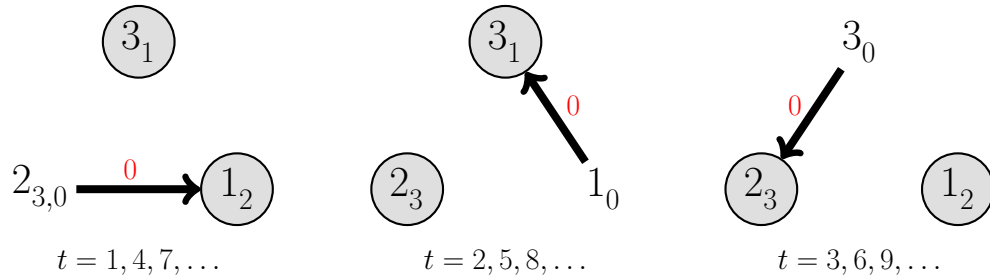
The role of fiat money. In our experiment, monetary trade emerged that involved a commodity. The focus on commodity money allows us to study centralized vs. decentralized trading arrangements through a parsimonious design where we do not need to add a fourth object that can serve as a medium of exchange. A

¹⁷This result is robust to making barter unattractive to one player by fixing types so if two players coordinate on barter, the third earns nothing in the entire session. We ran one session with 3 economies (9 subjects) and found similar results as in the other sessions (with rotation); the mean values are CM=0.07, DM=0.25, while barter trade=0.55.

related experiment focuses on fiat money to study trading arrangements with fixed vs. randomly changing counterparts when goods are non-storable (Bigoni et al., 2018). The open question is whether fiat money trade would emerge if it competed with storable goods serving as a money.

The FIAT treatment studies this case by building on BASELINE, where DM was the strongest. We add one intrinsically useless “good 0” (token) to player 2’s initial endowment. The token is costless to transport and can be exchanged for the player’s consumption good. This expands the strategy set, enabling fiat monetary trade where tokens circulate from island to island, and goods never move. To give the best chance for fiat money to arise in the limited session time, we minimized complexity by simplifying the action space. Players could transport only one object, and spend their token only to buy their consumption good away from their home island; those who did not travel could only acquire a token by offering their production good. This allows us to study the emergence of equilibria in which the token travels with buyers (see the “shopping equilibria” in Goldberg, 2007).

Figure 8: Asynchronous decentralized fiat money trade



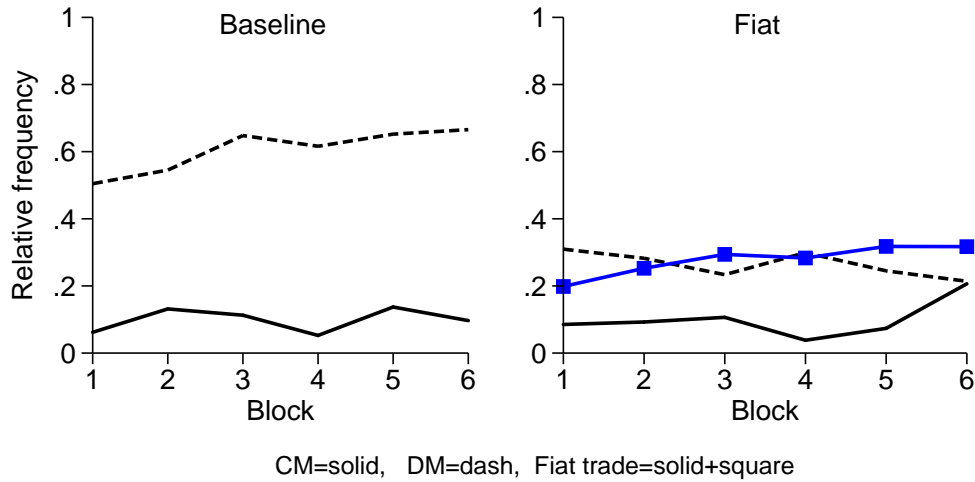
With three players, fiat monetary exchange requires a three-round trading cycle, as the token must circle all the way back to the initial spender (see Fig. 8). By contrast, DM is based on a two-round trading cycle. This implies that if fiat monetary exchange is an equilibrium, then it is Pareto-dominated by DM as the longer trading cycle reduces the player’s payoff to 4 points for the average round, as

compared to between 5.5 to 6 points in DM. The monetary literature asserts that fiat monetary trade emerges to expand the efficiency frontier. If so, then we should not observe any significant circulation of good 0, in the experiment.

Result 8. *With tokens, fiat monetary trade emerged and partly crowded out DM trade relative to BASELINE.*

Fig. 9 compares the average economy in BASELINE to FIAT.

Figure 9: FIAT vs. BASELINE



Notes: One obs.=one economy in a block (N=13 in each block for BASELINE; N=12 in each block for FIAT). CM (DM) = frequency of CM (DM) meetings; *Fiat trades*: frequency of fiat meetings.

The relative frequency of CM remains similar at 0.10, while DM falls from 0.61 to 0.26; only the second difference is statistically significant (two sided Wilcoxon-Mann Whitney ranksum test with exact statistics; CM, p-value=0.562, N1=13, N2=12; DM, p-value=0.009, N1=13, N2=12). By contrast the relative frequency of fiat monetary trade is 0.28, of which 0.06 are cases in which player 3 travels with fiat money to island 2, 0.08 in which player 1 travels to island 3, and 0.14 for player 2 travelling to island 1. As a result of the shift from DM to the less efficient fiat monetary trade overall efficiency decreased (two sided Wilcoxon-Mann Whitney ranksum test with exact statistics, p-value=0.086, N1=13, N2=12).

In FIAT, using tokens as money did not dominate commodity money trade. The relative frequency of CM is different from both DM and fiat trade, while DM and fiat trade are similar (two sided Wilcoxon-Mann Whitney ranksum test with exact statistics; CM vs DM, p-value=0.006; CM vs. Fiat, p-value=0.032; DM vs. Fiat, p-value=0.620, $N_1=N_2=12$). Evidence of a shift from CM and DM to fiat monetary trade also comes from a logit regression (not reported). Recall that player 2 trades in every round under CM and DM, but not under fiat trade. Hence, if tokens are used as money we should see that, if all three goods are available, player 2 trades less than in BASELINE. In FIAT the trading probability for player 2 fell to 0.56 from 0.73 in BASELINE, a significant decline (p-value=0.080, $N=874$).

6 Discussion

In the theory of money, a medium of exchange naturally emerges when specialization inhibits barter, and trade frictions forestall coordination on trading conventions that do not require money. In this situation, exchanging an object that cannot be consumed but can be easily re-traded is a profitable alternative. But, this argument is supported by assuming a bilateral matching process, while ruling out the possibility that individuals may seek to improve it. Here, we have lifted this restriction by developing a “travelling game” in which players can choose between decentralized asynchronous monetary trade, DM, and centralized synchronous non-monetary trade, CM. The laboratory data we have collected provide evidence in support of some of the intuitions of the monetary literature, but not of others.

Overall, the theory does a good job at organizing the data (Result 1). However, decentralized monetary trade prevailed in the frictionless baseline design, when in fact standard arguments would have predicted coordination on the socially efficient CM (Result 2). As CM is characterized by large payoff differentials, while DM is not, one could point to inequality aversion as the primary reason for this result.

And yet, non-monetary trade prevailed when subjects could coordinate their actions through pre-play communication (Result 6). This outcome reversal suggests that communication facilitated the high-earners' task to convince player 1 to go along with CM trade by travelling to island 2, even if by doing so they forego the larger payoff associated with DM trade. As equilibrium multiplicity gives rise to strategic uncertainty, we have argued that coordination problems are one of the possible explanations for the emergence of monetary trade. In all treatments, subjects could coordinate either on the efficient CM equilibrium or on DM, but only monetary trade was risk-dominant. We see a predominance of CM only when subjects could explicitly communicate with each other. This suggests a need to improve the theory of money by taking into account coordination and equilibrium selection problems.

Adding matching frictions—in REMATCH and in LARGE—supported coordination on monetary trade, but did not boost it above the frictionless baseline (Result 3). In fact, we see a bit of a shift from DM to CM and less coordination as compared to BASELINE (Result 5). Again, this is not what a monetary theorist would have expected. A possible explanation lies in the misalignment of players' incentives: player 1 prefers DM to CM, while the reverse holds true for players 2 and 3. We have evidence that both players 1 and 2 attempted to derail the equilibrium they least desired. These conflicting incentives make coordination on equilibrium inherently difficult, especially when counterparts are unstable, which may slow down learning. Matching frictions make counterparts unstable, which may also motivate subjects to repeatedly signal their preferred outcome by derailing their least preferred one.

Rotation of types led to a shift from monetary decentralized to non-monetary centralized exchange, even with matching frictions (Results 3 and 4). Since CM is socially efficient, this result is in line with monetary theory. However, CM did not prevail over DM in the rotation treatments, when in fact it prevailed in the CHAT treatment where there was *no* rotation. This suggests that rotation made CM more salient than in BASELINE, but coordination remained a problem. What made CM

salient with rotation? We have argued that, besides coordination problems, inequality concerns help to explain the emergence of monetary trade. Rotation re-aligns the incentives across participants, who can take turns in sharing the greater surplus offered by the socially efficient CM trade. This makes CM more attractive from a dynamic perspective. Type alternation is especially meaningful when groups are fixed throughout the session, which unlocks reciprocity schemes. In this case, one can view a session as an indefinite sequence of the travelling games in which endowments are redistributed at random points. According to this view, a subject's lower earnings in an early block can be compensated with higher earnings in subsequent blocks. There is support for this view in the data. When roles rotate, players 1 more frequently travel to meet players 2. Players 2 more frequently turn down the commodity money, good 1, to motivate others to coordinate on CM trade, which is more profitable for them.

Though these findings do not invalidate the fundamental intuitions from the theory of money, they do suggest improvements that might narrow the gap between theoretical intuitions and laboratory evidence. In particular, we wish to offer two considerations. The first one concerns the common view that money is adopted only if it overcomes the inefficiencies of alternative trading arrangements, and the impracticality of barter. Underlying this view is the idea that efficiency maximization is the overarching principle guiding the selection of trading arrangements. Our experiment suggests that coordination and distributional issues are also important considerations, a message that emerges also from different experimental designs (Camera and Casari, 2014; Camera et al., 2013). Commodity-money trade prevailed over efficient non-monetary trade when this yielded unbalanced payoffs (Result 2), a result that is partly reversed only when the structure of incentives was dynamically re-aligned by role-alternation in the session (Result 3). Moreover, when we added the option to engage in inefficient bilateral barter—without altering the structure of incentives—the low transport-cost good was often bartered, which completely crowded out other

forms of trade, including the efficient one (Result 7). It is perhaps reasonable that barter supplanted DM, which exhibits a more complicated, hence possibly less intuitive, dynamic pattern. But why did barter crowd out efficient CM? We can rule out aversion to inequality as an explanation. Barter payoffs are highly unequal, as one player type never consumes; moreover, in BARTER, types rotated during the session, smoothing out the large payoff differences of CM. A possible reason is that barter reduces strategic uncertainty for player 2. It is not possible to attain CM equilibrium without player 1 choosing to travel; knowing that player 1 is reluctant to do so given high travel costs, player 2 expects greater earnings from producing and bartering good 1 on island 1, instead of trading trilaterally. This matches the observation that the majority of barter trades involved player 2 visiting island 1 after producing good 1. Another possibility is that peer-to-peer exchange is more salient than multi-party exchange, possibly because it only requires bilateral coordination. Yet another motive could be a behavioral bias to acquire objects with the best intrinsic properties—in our case a low travel-cost. Data from the FIAT treatment supports this view. Adding a zero transport-cost token led to fiat monetary trade, crowding out the payoff-superior commodity money equilibrium (Result 8).

A second consideration concerns the role of two common assumptions in the foundations-of-money literature: the meeting process is bilateral, and players' incentives are perfectly aligned. With these assumptions, coordination on decentralized monetary trade becomes a natural outcome. The experiment lifted both restrictions and reveals that centralized non-monetary trade emerges when strategic uncertainty can be mitigated through explicit communication—even if players' incentives are conflicting—but also when players' incentives are re-aligned through alternation in economic tasks. In this sense the experiment shows that to better understand the emergence of monetary systems the theory of money should accommodate meeting processes and incentive structures that are less rigid than the ones currently assumed.

References

- Aliprantis Charalambos D., Camera Gabriele, Puzzello Daniela (2007). Contagion equilibria in a monetary model. *Econometrica* 75(1), 277-282.
- Bigoni Maria, Camera Gabriele, Casari Marco (2018). Money is More than Memory. *Journal of Monetary Economics* <https://doi.org/10.1016/j.jmoneco.2019.01.002>.
- Bigoni, Maria, Gabriele Camera, Casari Marco. Partners or Strangers? Cooperation, monetary trade, and the choice of scale of interaction. *American Economic Journal: Microeconomics* (forthcoming).
- Bolton Gary E., Ockenfels Axel (2000). ERC: a theory of equity, reciprocity and competition. *American Economic Review*, 90, 166-193.
- Brown Paul M. (1996). Experimental evidence on money as a medium of exchange. *Journal of Economic Dynamics and Control*, 20(4), 583-600.
- Camera Gabriele (2000). Money, search and costly matchmaking. *Macroeconomic Dynamics*, 4, 289-323.
- Camera Gabriele, Casari Marco (2014). The Coordination Value of Monetary Exchange: Experimental Evidence. *American Economic Journal: Microeconomics*, 6(1), 290-314.
- Camera Gabriele, Casari Marco, Bigoni Maria (2013). Money and trust among strangers. *Proceedings of the National Academy of Sciences*, 110(37), 14889-14893.
- Camera Gabriele, Noussair Charles , Tucker Steven (2003). Rate of return dominance and efficiency in an experimental economy,” *Economic Theory*, 22, 629-660.
- Camera Gabriele, Reed Robert, Waller Christopher (2003). Jack of all trades or master of one? Specialization, trade and money. *International Economic Review*, 44(4), 1275-1294.
- Corbae Dean, Temzelides Ted, Wright Randall (2003). Directed matching and monetary exchange. *Econometrica*, 71 (3), 731-756.
- Deck Cary A., McCabe Kevin A., Porter David (2006). Why stable fiat money hyperinflates: Results from an experimental economy. *Journal of Economic Behavior & Organization*, 61(3), 471-486.
- Diamond Peter (1984). Money in Search Equilibrium. *Econometrica*, 52(1), 1-20.

- Duffy John, Ochs John (1999). Emergence of money as a medium of exchange: an experimental study. *American Economic Review*, 89(4), 847-877.
- Duffy John, Puzzello Daniela (2014). Gift exchange versus monetary exchange: experimental evidence. *American Economic Review*
- Fehr Ernst, Schmidt Klaus M. (1999). A Theory of Fairness, Competition, and Cooperation. *Quarterly Journal of Economics*, 114(3), 817-868
- Fehr Dietmar, Heinemann Frank, Llorente-Saguer Aniol (2018). The Power of Sunspots: An Experimental Analysis. *Journal of Monetary Economics*, <https://doi.org/10.1016/j.jmoneco.2018.08.006>
- Fischbacher Urs (2007). Z-Tree: Zurich toolbox for ready-made economic experiments, *Experimental Economics*, 10(2), 171-178.
- Goldberg Dror (2007). Money with Partially Directed Search, *Journal of Monetary Economics*, 54(4), 979-993.
- Harsanyi John C., Selten Reinhard (1988). *A General Theory of Equilibrium Selection in Games*. MIT Press, Cambridge.
- Haruvy Ernan, Stahl Dale O. (2004). Deductive versus inductive equilibrium selection: experimental results. *Journal of Economic Behavior & Organization*, 53, 319-331.
- Heinemann Frank, Nagel Roesemarie, Ockenfels Peter (2009). Measuring Strategic Uncertainty in Coordination Games. *Review of Economic Studies*, 76, 181-221.
- Hellwig Martin F. (1993). The challenge of monetary theory. *European Economic Review*, 37, 215-242.
- Huber Jürgen, Shubik Martin, Sunder Shyam (2014). Sufficiency of an Outside Bank and a Default Penalty to Support the Value of Fiat Money: Experimental Evidence. *Journal of Economic Dynamics and Control*, 47, 317-337
- Kiyotaki Nobuhiro, Wright Randall (1989). On Money as a Medium of Exchange. *Journal of Political Economy*, 97, 927-954.
- Kiyotaki Nobuhiro, Wright Randall (1993). A Search-Theoretic Approach to Monetary Economics. *American Economic Review*, 83(1), 63-77.
- Kovenock Daniel, De Vries Casper G. (2002). Fiat Exchange in Finite Economies. *Economic Inquiry*, 40(2), 147-157
- Kocherlakota Narayana R. (1998). Money is memory. *Journal of Economic Theory*, 81, 232-251.

- Lian Peng, Plott Charles R. (1998). General equilibrium, markets, macroeconomics, and money in a laboratory experimental environment. *Economic Theory*, 12(1), 21-75.
- Lucas Robert E. Jr. (1984). Money in a theory of finance. *Carnegie-Rochester Conference Series on Public Policy*, 21, 9-46.
- Marimon Ramon, Sunder Shyam (1993). Indeterminacy of equilibria in a hyperinflationary world: some experimental evidence. *Econometrica*, 61, 1073-1107.
- McCabe Kevin A. (1989). Fiat money as a store of value in an experimental market. *Journal of Economic Behavior & Organization*, 12(2), 215-231.
- Ostroy John M., Starr Ross A. (1990). The Transactions Role of Money. Handbook of Monetary Economics, vol. 1, Benjamin M. Friedman and Frank H. Hahn, eds., Elsevier Science Publishers, 3-62.
- Rabin Matthew (1993). Incorporating Fairness into Game Theory and Economics. *American Economic Review*, 83, 1281-1302.
- Starr Ross M. (1972). The Structure of Exchange in Barter and Monetary Economies. *Quarterly Journal of Economics*, 86(2), 290-302.
- Townsend Robert (1980). Models of money with spatially separated players. In: Kareken, J., Wallace, N. (eds.) *Models of monetary economies*, 265-303. Minneapolis: Federal Reserve Bank of Minneapolis
- Van Huyck John, Battalio Raymond, Beil, Richard (1990). Tacit Coordination Games, Strategic Uncertainty, and Coordination Failure. *American Economic Review*, 80, 234-248.
- Weber Roberto A. (2006). Managing Growth to Achieve Efficient Coordination in Large Groups. *American Economic Review*, 96(1), 114-126.

Appendix: Existence of CM and DM equilibrium

Definition 1 (DM trade strategy). *Player 1 never travels, while players 3 and 2 alternate travelling with good 1 to islands 2 and 1, respectively. In every meeting, every player agrees to exchange their inventory for their consumption good. In a bilateral meeting, player 2 also agrees to exchange his production for good 1. All other possible trades are refused.*

Let v_j denote the DM equilibrium payoff for player j at the start of a period $s = 0, 1$, where 1 means odd, and 0 even. When no confusion arises, we omit the distribution of objects and the period s as an argument of v_j . We want to prove the following: *If*

$$c_1 < u < c_2(1 + \beta),$$

then decentralized trade is a Nash equilibrium. The equilibrium payoffs in a period $s = 0, 1$ are:

$$\begin{aligned} v_1 &= \beta^s u / (1 - \beta^2) \\ v_2 &= \beta^s (u - c_1) / (1 - \beta^2) \\ v_3 &= \beta^{1-s} (u - c_1) / (1 - \beta^2). \end{aligned} \tag{1}$$

In each period the actions of a player depend on his state (his inventory at the start of the period) and the distribution of goods at the start of a period. In equilibrium player 3 has good 1; player 1 has good 2; player 2 alternates holding good 3 to good 1 (in odd and even periods). All DM exchanges are bilateral and all players trade to acquire their consumption good. Player 2 also trades to acquire the low transport-cost good 1. Only the player with good 1 travels in a period. In odd periods $t = 1, 3, \dots$ player 3 visits island 2 to buy good 3 from player 2. In even periods $t = 2, 4, \dots$ player 2 visits island 1 to buy good 2 from player 1. This explains the payoff expressions v_1, v_2, v_3 . Given the experimental parameters we have $v_2 < v_1 < v_3$ in odd periods, and $v_3 < v_2 < v_1$ in even periods.

The Supplementary Information checks all possible deviations and demonstrates

that we need $u \leq c_2(1 + \beta)$ to ensure that player 1 has no incentive to deviate and visit island 2 in odd periods (to do trilateral exchange, which is never refused because all players always trade for their consumption good). We need $u > c_1$ or otherwise $v_2, v_3 < 0$.

Definition 2 (CM trade strategy). *In every period player 2 remains on island 2, while the other players travel to island 2 if and only if every player holds their production good. In every meeting, a player agrees to trade his production for his consumption good, and refuses to trade otherwise.*

We want to prove the following: *If $u > c_2$, then centralized trade is a Nash equilibrium, with payoffs w_i to type $i = 1, 2, 3$ given by*

$$w_1 = \frac{u - c_2}{1 - \beta} < w_3 = \frac{u - c_1}{1 - \beta} < w_2 = \frac{u}{1 - \beta}. \quad (2)$$

The CM strategy is time-invariant and depends on the distribution of goods across players. In CM, a player can deviate by not travelling to island 2, or by travelling but refusing to participate in the goods' reallocation scheme, thus retaining his inventory. Any equilibrium deviation leads to no trade (bilateral or trilateral) in the period, but does not affect the distribution of goods in the following period. The reason is that lack of consensus on the reallocation implies no trade. Subjects can propose to bilaterally trade, in this case, but the strategy in Definition 2 calls for trade only if it guarantees consumption so no trade occurs off equilibrium. Therefore, every unilateral deviation is suboptimal. Now note that player 1 has the lowest payoff in CM, and therefore we need $w_1 > 0$, hence $u > c_2$.

It should be clear that if $c_2 < u < c_2(1 + \beta)$, then CM and DM equilibrium coexist. In all treatments, except NO CM, both patterns of trade, decentralized and centralized, are equilibria because in the experiment $c_2 = 10 < u = 12 < c_2(1 + \beta) = 17.5$.

Now we prove that CM maximizes average payoffs but does not Pareto-dominate DM. The average payoff in CM is $w := \frac{u}{1-\beta} - \frac{c_1 + c_2}{3(1-\beta)}$, in each period, while in DM it is

$$v(s) := \frac{u - c_1}{3(1-\beta)} + \frac{\beta^s u}{3(1-\beta^2)},$$

with $v(0) > v(1)$, i.e., it is highest in an even period, $s = 0$, when two players consume. Hence, CM is socially efficient if $w > v(0)$, which simplifies to

$$u > u^* := \frac{c_2(1+\beta)}{1+2\beta}.$$

Since coexistence of DM and CM requires $c_2 < u$, and $u^* < c_2$, we have the result.

Finally, to show that no equilibrium is Pareto dominant note that $v_1 > w_1$ in any period because $c_2 < u < c_2(1+\beta)$ with our parameters. However, $v_2 < w_2$ and $v_3 < w_3$, always.